HYGROTHERMAL EFFECTS ON THE MECHANICAL PROPERTIES OF GLASS FIBRE-EPOXY COMPOSITE MATERIAL

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ABSTRACT

In this study, the hygrothermal effects on the mechanical properties of Glass Fiber Reinforced Plastic (GFRP) composite material was investigated. Unidirectional GFRP composite material was tested to determine tensile, flexure and Inter-laminar shear strength (ILSS) under both room temperature (RT) and hot-wet conditions. Prior to testing, hot-wet specimens were hygrothermally aged in an environmental chamber, maintained at 71^0C and 85 % relative humidity (RH) for 1%wt moisture absorption. Tests were performed in a computer controlled 50 kN servo-hydraulic test machine. For hot-wet tests, a split type environmental chamber was fixed to the machine which was also maintained at 71^0C and 85 % RH during the tests. The test data obtained was statistically analyzed to determine mean strength and B-basis design allowables. A comparative study was made to investigate the effect of moisture in the GFRP material at hot-wet and room temperature conditions, which showed a reduction in the strength. Presence of moisture in the epoxy matrix, in the fiber-matrix interface and the chemical attack of moisture on the glass fibers are the main reasons for reduced strength of GFRP material in hot-wet condition.

Key Words: GFRP, Moisture, Tensile, Flexure, ILSS

1. INTRODUCTION

The Glass Fiber Reinforced Polymer (GFRP) matrix composites industry today is experiencing significant growth as more products are made from reinforced plastics for greater durability, strength, and life. Thousands of products are now manufactured from reinforced plastics including building materials, sporting equipment, appliances, automotive/aircraft parts, boat and canoe hulls, and bodies for recreational vehicles. As the name implies, GFRPs are those with glass fiber reinforcement embedded in the plastic matrix. They incorporate fibers in various formats, such as multidirectional and unidirectional, continuous strand mat, chopped strand, long and short fibers strategically placed to produce parts that meet specific requirements in terms of stiffness and strength. Generally,

laminated composites are preferred to be used for high-performance structural applications due to their high specific strength and high specific stiffness.
In service, composite materials are exposed to varying humidity and temperature conditions[1,2]. Over a long duration of time, composites absorb moisture [3,4] and it affects mechanical properties of these materials significantly[4-7]. In this study, the effect of moisture on the mechanical properties of GFRP composite material was investigated. Unidirectional GFRP composite material was tested to determine tensile, flexure and ILSS properties both in RT and hot-wet conditions. Tests were performed as per ASTM standard. Hot-wet specimens were hygrothermally aged for moisture absorption. The test results obtained were statistically analyzed to determine mean strength and B-basis design allowables. Results obtained are briefly discussed and conclusions were drawn with respect to strength degradation by moisture.

2. EXPERIMENTAL

Unidirectional R-glass fiber in V913 polymer matrix (GFRP) was used in this investigation. The nominal ply thickness was about 0.24 mm and the fiber volume fraction was about 0.5. Standard tensile, flexure and ILSS test specimens were fabricated from these materials as per ASTM [8-10] test standard specifications. Hot-wet test specimens, prior to testing, were hygrothermally aged in an environmental chamber which was maintained at 71^0C ± 2 ^{0}C and 85% ± 4 % Relative Humidity (RH) for 1%wt moisture absorption . Specimens were then removed from the chamber and tested for their mechanical properties. All the tests were performed in a computer controlled 50 kN servo-hydraulic test machine under stroke control mode with a constant cross-head speed of 1mm/min. For hot-wet tests, a split-type environmental chamber was fixed to the test machine. Saturated steam and hot air were passed inside the chamber to maintain 71^0C ± 2^0C and ≥ 85% RH. The temperature and RH in the test chamber was monitored by a thermocouple and a hand held humidity meter, respectively. A photograph of the hot-wet test set-up is shown in Fig.1. Unlike metals, composites are known to exhibit a large scatter in test results. Thus, statistical analysis of the strength data is invariably associated with testing and evaluation of composite materials[11-13]. In this investigation, about 18 specimens (06 specimens each from each batch) for each property and environmental condition were tested to obtain the average ultimate strength. The Mean, Standard Deviation (SD) and the B-Basis design allowable were determined.

3, RESULTS AND DISCUSSION

The mean ultimate tensile strength (UTS) of R-Glass GFRP material under RT and hot-wet conditions are shown in Fig. 2. On an average, UTS was reduced by about 8% . Explosion mode of failure was observed in most of the test specimens as shown in Fig. 3. The ultimate flexural strength of GFRP material under RT and hot-wet conditions are shown in Fig. 4. On an average, flexural strength was reduced by about 11%. Typical failure modes of the flexural test specimens are shown in Fig. 5. The Inter-laminar shear strength (ILSS) of GFRP material under RT and hot-wet conditions is shown in Fig. 6. ILSS was reduced by about 13%. Typical failure modes observed in ILSS test specimens are shown in Fig. 7. It has been shown that moisture plasticizes the epoxy matrix and reduces the glass transition temperature[7,14,15]. Also, presence of moisture at the fiber-matrix interface reduces the strength of the composite material[5]. Thus, moisture generally affects any property, which is dominated by the matrix and/or interface. Hence, being matrix dominated properties, ILSS strength is expected to be lower in hot-wet condition. However, the tensile strength and flexure being a fiber dominated property, the strength reduction occurs only if the fibers themselves are affected by moisture. It has been shown that moisture can cause degradation at the fiber level in glass fibers [16,17]. Degradation is initiated by moisture-extracting ions from the fiber, thereby altering its structure. These ions combine with water to form bases, which etch and pit the fiber surface, resulting in flaws that significantly degrade strength and can result in premature fracture and failure of the fibers. This is probably the main reason for observed tensile strength reduction in hot-wet conditions.

CONCLUSIONS

Following conclusions may be drawn from the results obtained in this investigation:
1. Tensile, flexure and Interlaminar shear strength of the GFRP material is reduced by presence of moisture. The strength reduction varies from about 8% to 13% depending on the type of property.
2. Presence of moisture in the matrix, fiber-matrix interface and also the moisture attack on the glass fibers are all thought to be the main reason for reducing the mechanical properties under hot-wet condition.

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Figure 1. A photograph of the hot-wet testing of composite materials

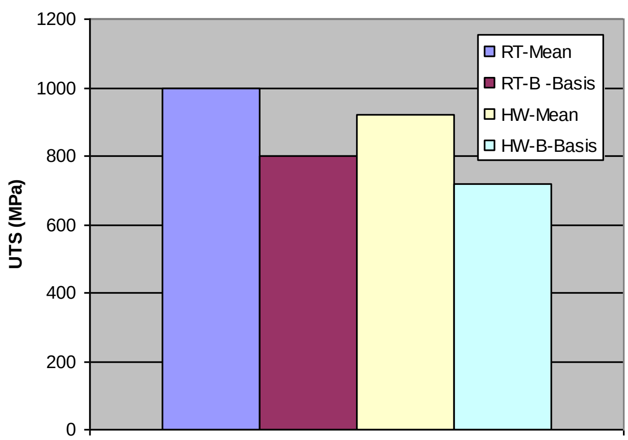

Figure 2. Effect of moisture on the UTS

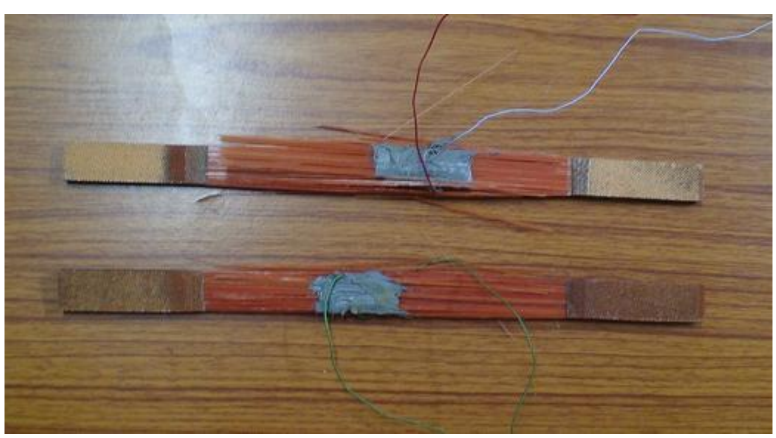

Figure 3. Typical tensile failure mode

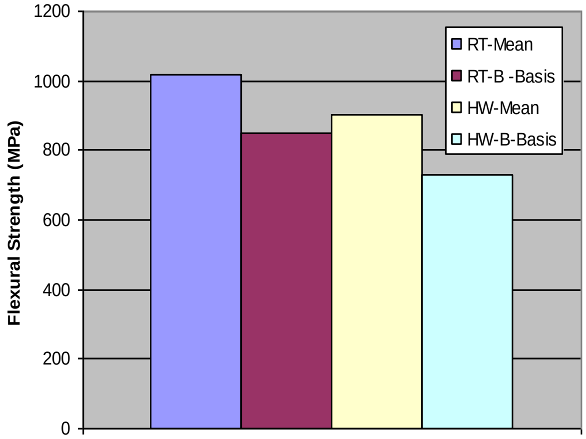

Figure 4. Effect of moisture on the Flexural strength

Figure 5. Typical flexural failure mode

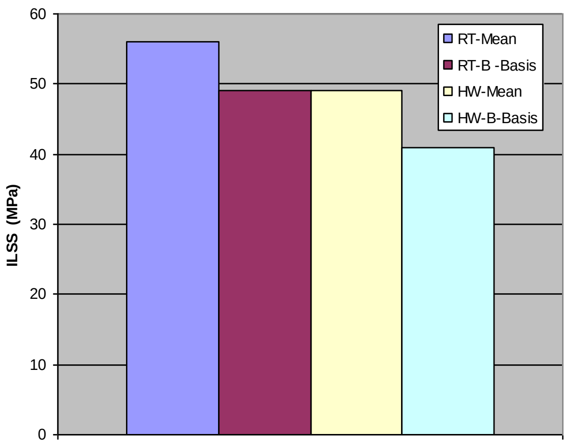

Figure 6. Effect of moisture on the ILSS

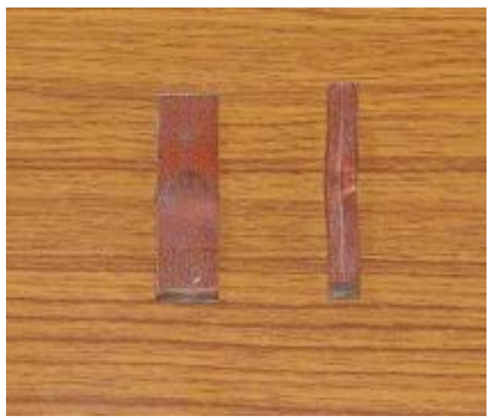

Figure 7. Typical ILSS failure mode